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Night Vision Goggles Objective Lens Focusing Methodology

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ABSTRACT
Before performing an airborne mission that uses night vision goggles (NVGs) , aircrew must properly set the NVG's various adjustments: interpupillary distance, tilt, eye relief, height, eyepiece and objective lens focus. Currently, aircrew use a Hoffman 20/20 test unit to pre-focus their NVG objective lenses at optical infinity before boarding their aircraft. They may also refocus their objective lenses while in the cockpit and during the course of the mission. This paper examines observers' abilities to resolve targets of different sizes, viewed through NVGs, as a function of different pre-focused distances corresponding to "focusing errors".

INTRODUCTION

Objective: The ultimate objective of this effort was to determine if there was any difference in NVG visual acuity depending on whether NVGs were focused using a Hoffman 20/20 test system or distant ambient objects. However, due to the unavailability of a Hoffman 20/20 test unit during the time available to conduct this study, the secondary objective was to determine the sensitivity of NVG visual acuity to the distance of objects used to focus the NVGs.

Background: The Hoffman 20/20 test system was designed to provide a distant (infinity) optical image of a test pattern to determine the level of resolution/visual acuity available in an NVG and determine that the NVG could focus at infinity (objective lens optical adjustment). It is currently being used to pre-adjust objective lens focus prior to flight to insure the NVGs are properly focused. However, the Hoffman 20/20 uses a relatively narrow-band light emitting diode (LED) illuminator which may result in a different objective lens focus than what would be obtained under typical broad-band night illumination. In addition, pressure changes due to altitude or misadjustment due to accidental impact of NVGs on the canopy may destroy the objective lens focus obtained during the preflight adjustment using the Hoffman 20/20. The question is "can aircrew readjust the NVG objective lenses in-flight and obtain focus (i.e., visual acuity) at least as good as they obtained using the Hoffman 20/20?" Two studies were conducted to provide some indirect information to aid in answering this question. The first study was conducted to determine the relative sensitivity of observers' visual acuity to intentionally defocused objective lenses and the second was conducted using a single trained observer to assess focusing sensitivity using a different methodology. The second study was prompted by the inconclusiveness of the first study.

METHOD - STUDY ONE

Observers

The trained observers were one female and two males, highly experienced with the operation of NVGs. They ranged in age from 38 to 49 years, each having normal (20/20) or corrected-to-normal binocular visual acuity.

Stimuli

Landolt C's - The test stimuli were closely-sized computer-generated, high contrast (70% Michelson; Farrell & Booth, 1984) Landolt C's (National Academy of Sciences, 1980) printed using a high resolution, photo-grade laser printer. The print out of each target was mounted on 18 cm x 18 cm (7" x 7") squares of foam board. Each target varied in gap size and represented, when converted, a specific Snellen visual acuity value (20/xx). The back of each target was labeled with four different bar code patterns. Each bar code contained identification information for that particular target such as target number, target type, the corresponding visual acuity (20/xx), the target contrast, and the gap's orientation. For each experimental trial, a Landolt C was placed in the center of a larger foam board surround 56 cm x 56 cm (22" H x 22" L). This surround was secured to the front of a black light-tight wooden box. The box measured 66 cm H x 56 cm W x 36 cm L (26" H x 22" W x 14" L) and sat on top of a stand. The surround had the same reflectance as the background of the Landolt C's. This box housed a bar code scanner/reader used to automate the recording of Landolt C target information. The light-tight box prevented the incompatible red laser beam from the bar code scanner from affecting the NVGs. The bar code reader connected directly to a computer at the experimenter's station. The entire set up was positioned at 54.9 meters (180'; near NVG optical infinity) from the observer. A four button response box was used to record the observer's response (gap up, down, left or right). The computer recorded the button press response and Landolt C bar code information as well as other pertinent information.

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Apparatus

NVGs - Participants viewed the target stimuli using a pair of ITT model F4949D (SN 3873) NVGs. The goggles had a gain of approximately 5600 as measured using the Hoffman ANV-120 NVG Test Set. Before the start of each test session, the optical alignment of the NVGs was verified using the Hoffman ANV-126 Night Vision Tester.

Each test session was conducted in a light-tight laboratory. The observer was seated with the NVGs secured in a stationary mount directly in front of them. The observer was able to adjust the NVGs to the proper height for viewing. An external regulated power supply was used to energize the goggles.

The NVG eyepieces were preset to -0.5 diopters using a Keuffel & Esser dioptometer. At the beginning of each test session the observer would set up and pre-focus the NVGs. After dark-adapting for 10 minutes, the NVGs were powered on. The observer focused the objective lenses by viewing a large, high-contrast square-wave resolution chart.

Illumination sources and Illumination levels - The stimuli were illuminated using a moon lamp outfitted with an adjustable 2856K color temperature incandescent bulb (MIL-L-8576A, 1986). Metal apertures were used to achieve the desired illumination level. Using apertures to adjust illumination intensity did not affect the 2856K color temperature. The illumination on the Landolt C's was 4.0×10^{-3} lux (3.72×10^{-4} fc). The output from the NVGs was approximately 5.14 nits (1.5 fL). Since the observer was so far away from the stimulus area, the surrounding area was for the most part dark. To illuminate a larger portion of the NVG's field-of-view, the observer looked through a large, white 122 cm x 153 cm (4' x 5') illuminated mask having a 15 cm x 20 cm (6" x 8") aperture located about 366 cm (12') in front of their viewing position. This illuminated area also produced about 1.5 fL goggle output. The near and far fields were a good brightness match when viewed through the goggles.

Procedure

Each of the three observers completed 240 trials (24 trials x 10 Snellen acuity levels) on each of three days. For a particular day, the observer focused his/her goggles at one of three focus distances. The order of the focus distances were counterbalanced across observers. During each trial, the observer, at 54.9 meters (180'), attempted to identify the orientation of the Landolt C gap with choices being left, right, up, and down.

Eight repetitions, with randomly presented orientations, were performed at a particular acuity level followed by eight more repetitions at another acuity level. This was repeated 10 times, in a random fashion, with each acuity level used once to complete a session. Three sessions were conducted per day to achieve the total of 240 trials.

For each trial, the experimenter, using pre-determined randomized stimuli ordering, placed a Landolt C onto a small ledge centered on the surround while keeping it blocked from the observer's view. The ledge centered the 'C' and was not visible when viewed through the NVGs. The experimenter pressed a switch to scan the bar code on the back of the target. The experimenter would then move away from the Landolt C and the observer had about four seconds to view the stimulus. At the end of the four-second interval, the computer would beep an alarm and the experimenter would immediately block the stimulus from the observer's view. The observer would announce their response and it was recorded. The observer was not provided with any feedback on their performance.

RESULTS - STUDY ONE

Due to recording problems, there were 10 groups of 24 trials (i.e., combination of observer, focus distance, and acuity) where responses from less than 24 trials were obtained. Table 1 contains the percent of trials in which the orientation was correctly identified. Chance alone would result in 25% correctly identified trials. It is assumed that percents in Table 1 that are less than 25% would approach 25% with a sufficient number of trials. The percents from Table 1 were transformed to adjusted for chance values and are shown in Table 2.

Table 1. Percent correct trials (N = 24) for each observer, focus distance, and acuity.

Snellen Acuity (20/xx)	**Observer #1 Focus Distance (ft)**			**Observer #2 Focus Distance (ft)**			**Observer #3 Focus Distance (ft)**		
	80	**100**	**180**	**80**	**100**	**180**	**80**	**100**	**180**
13.50	29	42	29	21	29	21	29	29	29
15.17	21	17	42	42	46	33	33	33	46
17.04	13	25	25	25	42	42	35	33	38
19.15	33	33	30	38	38	25	54	46	50
21.52	48	50	54	46	43	38	42	21	42
24.18	58	58	64	54	46	67	75	58	63
27.16	83	79	58	67	58	83	96	83	96
30.52	79	88	88	63	83	100	96	92	96
34.29	96	100	96	96	92	92	100	100	96
36.35	94	100	96	100	83	100	100	100	100

Table 2. Percent correct (N = 24) adjusted for chance. Percents in italics were not used for modeling.

Snellen Acuity (20/xx)	**Observer #1 Focus Distance (ft)**			**Observer #2 Focus Distance (ft)**			**Observer #3 Focus Distance (ft)**		
	80	**100**	**180**	**80**	**100**	**180**	**80**	**100**	**180**
13.50	*6*	*22*	*6*	*0*	6	*0*	6	6	6
15.17	*0*	*0*	*22*	*22*	28	*11*	11	11	28
17.04	0	0	0	0	22	*22*	13	11	17
19.15	11	11	7	17	17	0	39	28	33
21.52	30	33	39	28	24	17	22	0	22
24.18	44	44	52	39	28	56	67	44	50
27.16	78	72	44	56	44	78	94	78	94
30.52	72	83	83	50	78	100	94	89	94
34.29	94	100	94	94	89	*89*	100	100	94
36.35	92	*100*	94	100	78	*100*	*100*	*100*	100

The non-italicized values in Table 2 were converted to normal equivalent deviates (NED). An NED is the value of a standard normal variable whose cumulative probability (expressed as a percent) would equal the percent correct adjusted for chance. Since an NED cannot be computed for 0% or 100%, 0% was set to 1% and 100% was set to 99%. The NED values were used as the dependent variable in a linear regression with acuity as the independent variable (a linear relationship is assumed). This procedure is referred to as Probit Analysis (Finney, 1980, Pinkus & Task, 1989). The estimated NED = b_0+b_1*acuity was transformed back to percents. For each observer and focus distance, the acuity level that corresponded to 50% and 75% correct, adjusted for chance, was determined and shown in Table 3.

Table 3. Snellen acuity levels corresponding to 50% and 75% correct, adjusted for chance.

	50 P_A			**75 P_A**		
	Focus Distance					
Observer	**80**	**100**	**180**	**80**	**100**	**180**
#1	26.2	25.0	26.3	29.9	27.8	29.8
#2	26.3	26.4	24.5	29.8	32.9	26.3
#3	22.0	24.2	22.2	25.4	27.8	26.3
Mean	24.8	25.2	24.3	28.4	29.5	27.5
Std	2.5	1.1	2.1	2.6	2.9	2.0

Table 4. Analysis of variance results.

P_A	**Source**	**SS**	**DF**	**SSE**	**DFE**	**F**	**p**
50	Focus Distance	1.09	2	5.19	4	0.42	0.6834
75	Focus Distance	6.13	2	21.75	4	0.56	0.6085

The acuity levels corresponding to 50% and 75% correct were used as dependent variables in a one factor (focus distance) repeated measures analysis of variance. Results are shown in Table 4.

METHOD - STUDY TWO

Study Two was substantially simpler and faster than Study One and the technique can be more directly applied to answer the original question regarding the Hoffman 20/20. Since it was apparent from the first study that there was no difference in visual acuity performance for the range of defocus distances selected, a different approach to the focusing issue was devised. Focusing the objective lenses of NVGs is done by physically moving the objective lens of the NVG closer to or further from the image intensifier tube. At infinity focus the objective lens is at its closest distance to the tube; as objects closer than infinity are brought into focus the objective lens must move away from the image intensifier tube. This movement is very small and difficult to measure but provides a means of determining change in focus position. A single trained observer focused the NVGs at six different distances (3, 6, 12, 18, 30 and 46 meters or 10', 20', 40', 60', 100' and 150', respectively) 10 times each for each of two focusing stimuli. The first stimuli was a grating somewhat similar to the grating target used in the Hoffman 20/20. The second stimuli was a point source of infrared light. A digital caliper was used to measure the overall length of the NVGs for each of the 120 focus settings (6 distances, 10 repetitions, 2 focus stimuli). Using first-order lens imaging theory (Hecht and Zajac, 1975, p.-168) it is possible to derive a theoretical equation to relate the NVG objective lens movement to the distance of the stimulus to be focused. This theoretical movement relationship can then be compared to the obtained results. It was hypothesized that there would be no difference in focusing ability between the grating and point source stimuli.

RESULTS - STUDY TWO

The results for Study Two are shown in tabular form in Table 5. The data in Table 5 are the average (over 10 repetitions) lengths of one NVG ocular for each of the distance and stimuli conditions. The theoretical equation only relates the relative movement of the objective lens with respect to focus distance so it was necessary to "anchor" the equation. The objective lens should have been closest to the image intensifier tube for "infinity" focus. Based on the results of Study One, there was no difference in visual acuity (focus) between 80', 100', and 180' indicating that these distances were essentially "infinity" as far as the NVGs were concerned. Therefore the 150' distance was taken as the "anchor" point. The theoretical data was produced by setting the 150' data point to be equal to the average of the 20 focus settings (10 for point source and 10 for grating) obtained at 150' (as can be seen in Table 5). Results are in Figure 1 and Table 5.

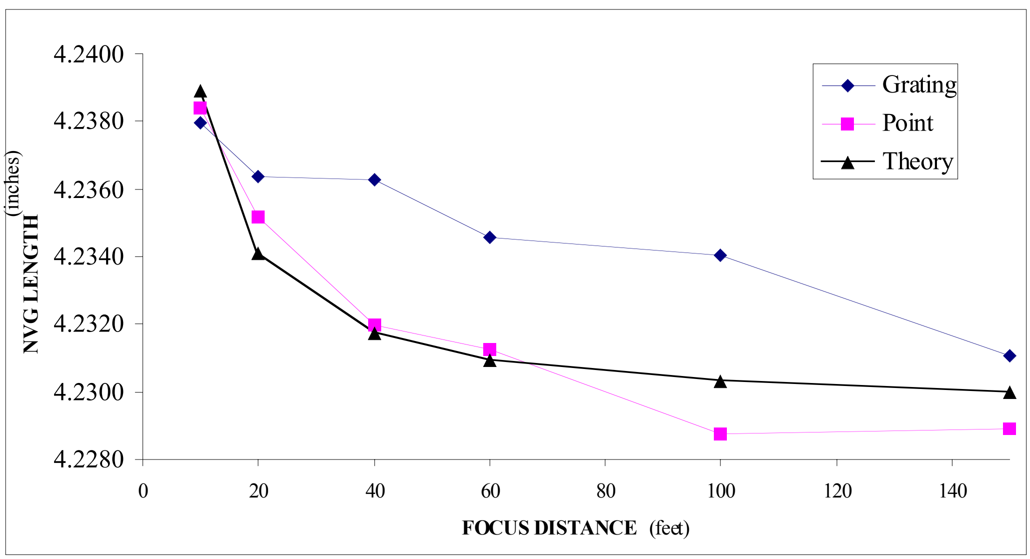

Figure 1. Graphical results of NVG ocular length as a function of focus distance for two focusing stimuli.

Table 5. NVG length as a function of focus distance and focus stimuli (all data in inches)

Distance	Grating	Point	Theory
10'	4.2380	4.2384	4.2389
20'	4.2364	4.2352	4.2341
40'	4.2363	4.2320	4.2317
60'	4.2346	4.2313	4.2309
100'	4.2341	4.2288	4.2303
150'	4.2311	4.2289	4.2300

DISCUSSION and CONCLUSIONS

The first study described in this paper attempted to assess focusing sensitivity of the NVGs by assessing visual acuity for different levels of defocused objective lens settings. Previous theoretical calculations indicated the depth of field of the NVGs is such that a focus error should be noticeable around the 100' or so, distance. However, it is clear from the results of the first study that there was no statistically significant difference in visual acuity for the three focus distances investigated. The repeatability and reproducibility of NVG visual acuity measurements has not been determined but it is apparent that there is a certain amount of variance associated with measuring NVG visual acuity. This makes it difficult to detect small differences in parameters that may affect visual acuity. If a broader range of defocus distances were investigated (which needs to be done) it is expected that there would be a significant effect on NVG visual acuity. The Probit technique, used to obtain visual acuity, is extremely fatiguing and time consuming for observers which is what led to the technique developed in the second study.

Since the primary issue is whether or not the stimulus used to focus the NVGs makes a difference in the quality of the focus obtained, we believe the technique developed in the second study provides a better and more convenient means to address the issue. Surprisingly, the second study resulted in a statistically significant difference in focus settings (all six distances; analysis of variance) between focusing on a distant (150') point source versus a square-wave grating. Both methods produced similar results at 10' and at the distant 150' but the grating stimulus lagged behind the point source for the intermediate distances. We have no explanation for this effect but it deserves a bit more attention in the future. For the "optical infinity" (150') distance, there was no statistically significant difference between the grating stimulus and the point source stimulus. This would imply that the quality of focus should be the same, independent of the focus stimulus (providing it is a reasonable stimulus). Since this second study involved only one highly trained observer it would be well worth while to repeat this technique with a larger number of trained observers and with a broader range of focusing stimuli and lighting levels. We believe that this technique, after some refining, is probably the best method of determining the focusing differences, if any, between using the Hoffman 20/20 and using ambient objects for focus adjustment. Future plans are to refine the technique in the laboratory and then try it out in the field.

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BIOGRAPHIES
Alan Pinkus has been a US Air Force research psychologist since 1982. As a human factors engineer, he has worked on major systems including the Royal Saudi Air Force KE-3 tanker, Gunship 2, LANTIRN, Air Force One and Joint-Stars. As a researcher, he has worked in the areas of image display metrics, night vision goggles, apparent motion, aircraft lighting, transparency analysis, vision from space, workload assessment and has lectured for NATO AGARD in Europe. Alan has a BS Degree (Wright State University, 1974), an MA (University of Dayton, 1980) and a PhD (Miami University, 1992), all in Experimental Psychology. He holds eight patents in the area of night vision goggle ancillary devices and has over 25 publications. He is a member of SAFE, Association of Aviation Psychologists, the Human Factors and Ergonomics Society (Southern Ohio Chapter) and is active in the American Society for Testing and Materials Subcommittee (ASTM) F7.08 on Transparent Enclosures and Materials.

H. Lee Task (please see the associated session paper entitled, "Integrated Panoramic Night Vision Goggles Fixed-Focus Eyepieces: Selecting A Diopter Setting")